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TITLE: An ISOCAM based search for brown dwarfs in the Hyades.

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I. Introduction

- Why are brown dwarfs interesting?
- Why Hyades?
- The ISO connection

Brown dwarfs (BD), although self-gravitating gaseous bodies, are not massive enough for sustained nuclear fusion and span the range of masses between the lowest-mass stars and planets. Thus, BDs are a vital component of both the star-formation and the planet-formation mechanism and are relevant to our understanding of both processes. Additionally, BD provide tests of our understanding of the physics of degenerate bodies for a thermodynamic regime different from white dwarfs.

Over 100 BDs have now been identified as either single ``free-floating'' objects or as companions to nearby stars. Further broad-band imaging and optical/IR spectroscopic studies has segregated the BDs into two types: (1) the new ``L'' spectral class objects, which are differentiated from the ``M'' dwarfs by redder broad-band colors, the depletion of Ti and Vanadium oxide bands, and an increase in strength of the water and alkali metal absorption. And (2) the so-called ``T-'' type object which show, in addition, methane absorption and neutral (sometimes negative) broad-band near-IR colors.

Deciphering the true nature of these objects is made simpler when additional information is present. For this reason, brown dwarfs in open cluster in general and in Hyades in particular are specially valuable as the age, distance and chemical composition of these dwarfs are well-constrained. In the very young clusters (eg Pleiades) the brown dwarfs are seen in the earliest, most luminous, and hottest stage and appear similar to late-type stars. By contrast, at the age of Hyades (~600 Myr) all BD with masses $\leq 0.06 M_{\text{sun}}$ will have cooled to temperatures below ≤ 1500 K and are easily discernible. This very characteristic, however, also makes it difficult to detect BDs in the

Hyades.

The cooled environment of ISO allowed us to survey the low-mass component of the Hyades cluster with flux sensitivity unavailable from ground-based telescopes.

II. Summary of The ISO observation program

We use ISOCAM's micro-slewing Astronomical Observation Template (AOT) to perform ``pseudo-beam switching'' observations by restricting the offset of the telescope in one of the micro-slewing directions to 0 arc-seconds. Our simulations with the Program Generation Aid (PGA) package reveals that this observing procedure is more efficient (requires less overhead time) than the beam-switching AOT available for the ISOCAM. In addition, the targets were grouped in pairs or triplets which allowed us to further improve the observing efficiency by concatenating the observations of an object with other targets in the same group.

We use the $6\sqrt{\text{arcsec}}$ pixel field-of-view lens for a total field coverage of $3\sqrt{\text{farcm}^2} \times 3\sqrt{\text{farcm}^2}$. For stars grouped in pairs, we spend a total of 103 minutes per pair (total time including overhead) in four, approximately equal, 25 minute intervals. The target stars in the pairs are alternated between each interval. The stars grouped in triplets are similarly observed in 25 minute intervals with the exception that the two observations of the same star are separated by 50 minutes rather than 25 minutes.

For each 25 minute segment, we beam-switch $24\sqrt{\text{arcsec}}$ ($\sim 4\sqrt{\text{pixels}}$) between the initial position and an offset in either declination or right ascension. The exposure time is 16 exposures $\times 10.08$ seconds per exposure. This gives us 4 cycles of pseudo beam-switches (in the micro-slewing AOT) which equals 8 pairs of ON-OFF observations each with 8 ON and 8 OFF exposures. This leads to a total of 128 frames per star for each 25 minute segment.

An additional 12 exposures are prefixed to the first segment of the pair (or triplet) for detector stabilization. We occasionally receive an ``extra'' exposure or two between the beam-switches; Thus, the resulting total exposures (per star) usually number more than 128 frames.

III. Data Reduction Procedure

Step 1: If necessary, subtract a two time constant exponential decay from the first of the LW1 dataset. The time constants for the exponential decay are obtained from a fit to the median values of the frames.

Step 2: Construct a reference pixel response function, RPRF, by using the Hyades target star. The RPRF describes the modulation of the signal within a single pixel as the star is noddod between the ON- and the OFF-beam positions.

Step 3: We assume that the response function of any other pixel in the data cube, PRF_i , can be modeled by linearly scaling the RPRF.

Step 4: The best-fit linearly scaling parameters (in Step 3) are obtained by minimizing the χ^2 between the observed data and a scaled RPRF. The amplitude of the scaling determines the flux of the source.

Initially, all data (including glitch events) are used, resulting in artificially high values for the reduced χ^2 . We improve the initial fit by rejecting the most discrepant point (in step 3) under the assumption that the deviant frame (in the PRF) is corrupted by a glitch event. The best fit (step 4) is recomputed. This process is repeated until rejecting the most deviant frame from the PRF shows no significant improvement in the value for the minimum χ^2 . Significance, in this context, is defined via the F -test

Step 5: Calibrate the scaling factors (step 4). We obtained independent ground-based data on the program Hyads to derive the flux calibration for this reduction procedure (figure here).

IV. Results

1. Identifying the ``interesting'' candidates.

We identify possible brown dwarfs members of Hyades by considering those stars which appear on the ISO images but are not seen on POSS plates. Five stars qualify under these criterion.

2. An ISO detection (and optical non-detection) cannot establish the low-mass nature of the sources. We started a program to obtain ground-based photometry of these five sources. Ground-based, near-IR data can:

- * provide a more accurate SED of the sources.
- * with high spatial resolution, we should be able to distinguish between galactic and extra-galactic sources.
- * provide a better estimate of distance by establishing a more accurate near-IR color and hence an intrinsic type.

3. The combined ISO near-IR data showed:

- * two objects were not detected in the near-IR images.
- * two objects appear to be consistent with late-type M-dwarfs, likely to be low-mass members of the Hyades.
- * 1 object has colors which are consistent with late-type L-dwarfs!

4. Candidates.

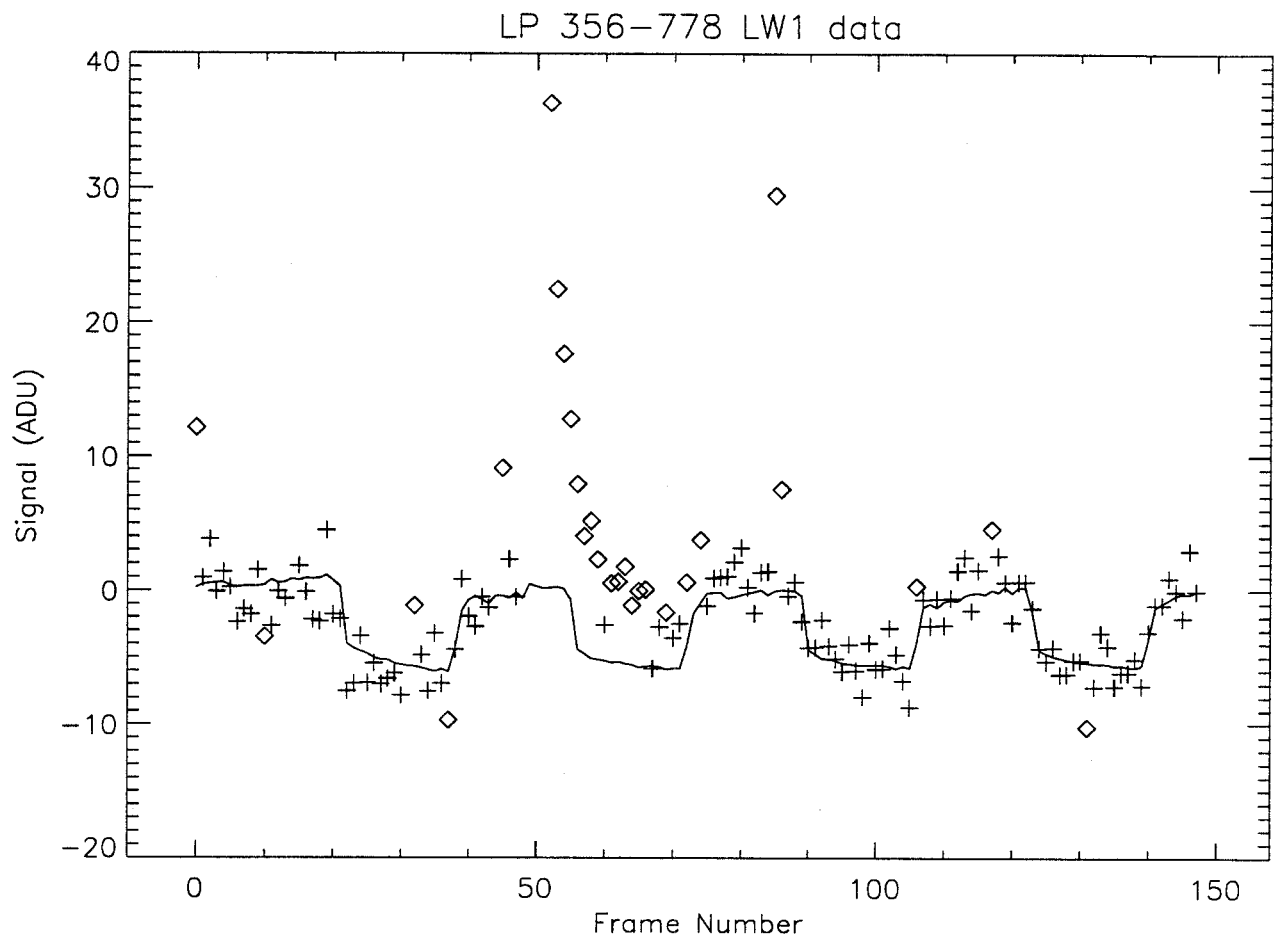
Only one object remains after ground-based follow-up data. The near-mid IR colors of the target are consistent with low-mass L-type objects which at the age of Hyades will be brown-dwarfs.

The object is, unfortunately, also consistent, albeit with very low probability, with a compact extra-galactic source.

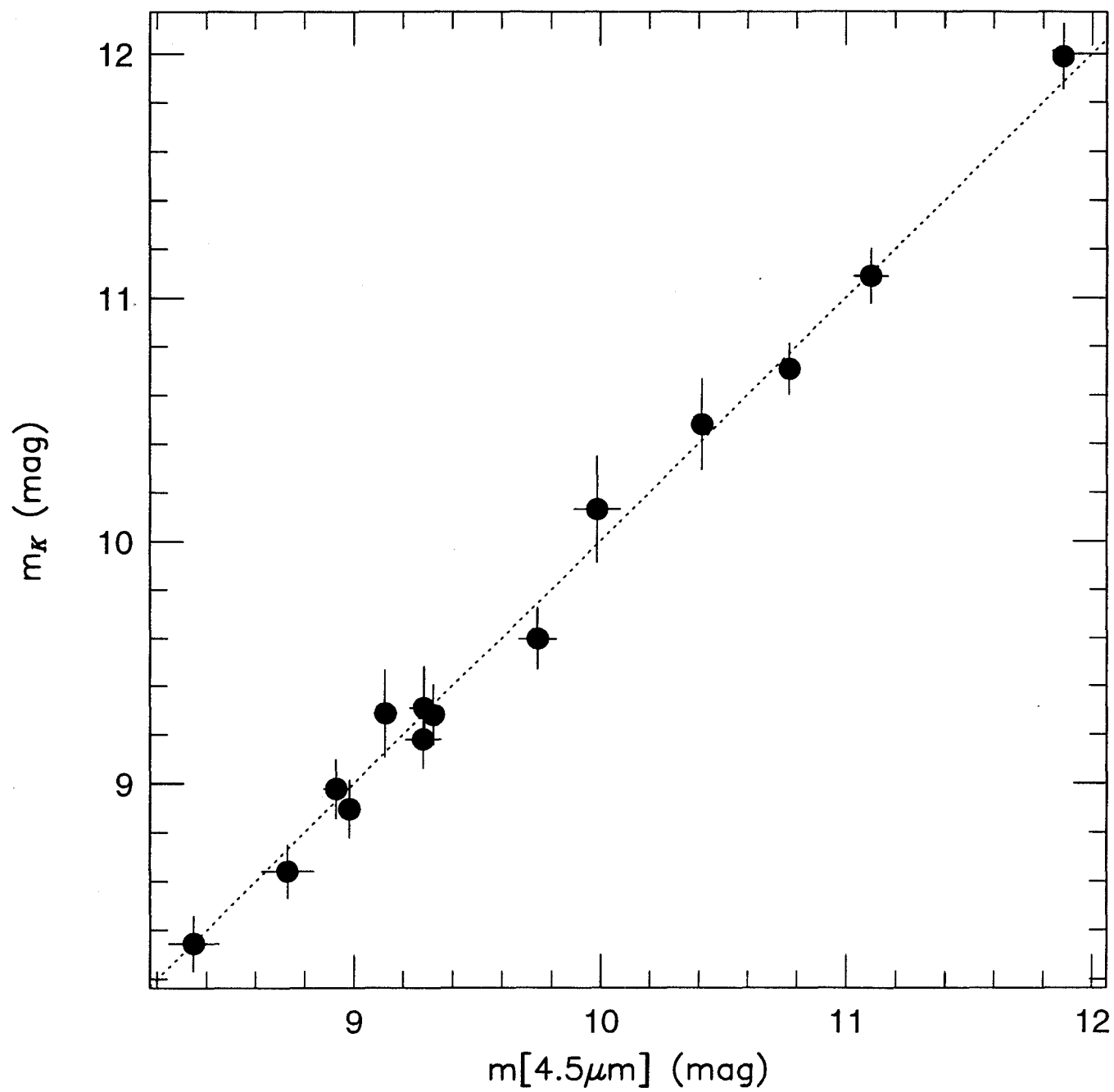
Future, high spatial resolution images of the source can further

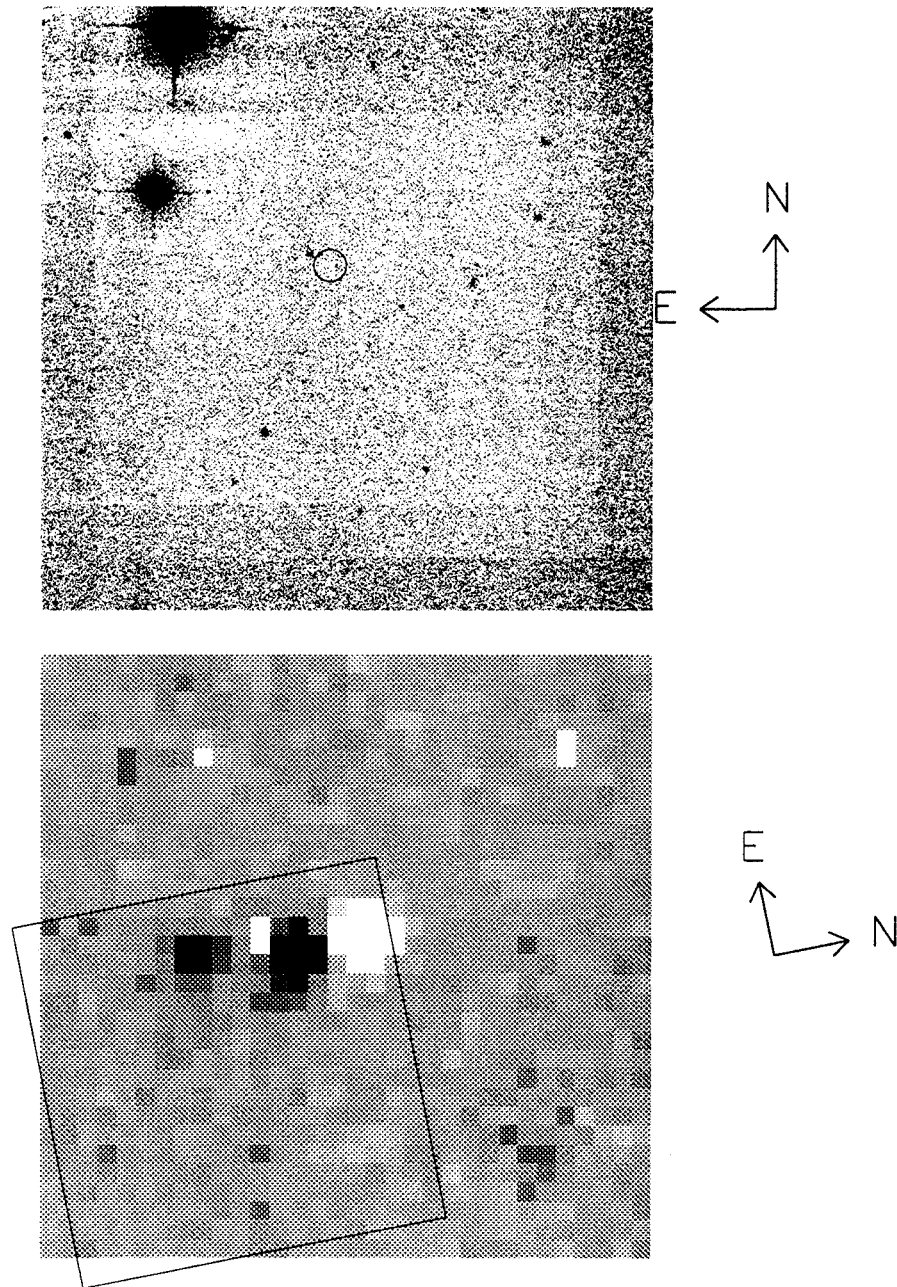
confirm/reject its extra-galactic nature.

In all, 1/23 brown-dwarf objects in the Hyades are consistent with the current estimates for the space density of these stars.



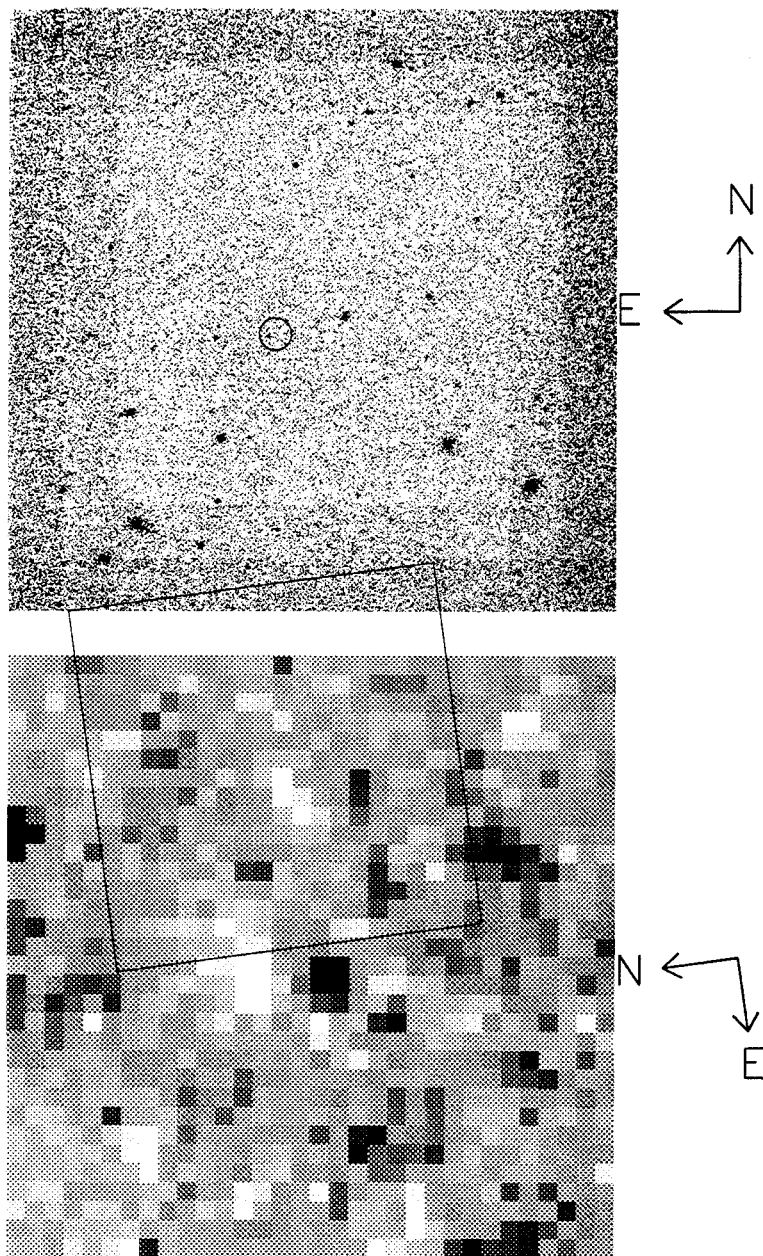
Hyades LW1 calibration





GH7-89

Fig. 5.— The GH 7-89 field, K-band image.



RE77

Fig. 4.— The Re 77 field, *K*-band image.

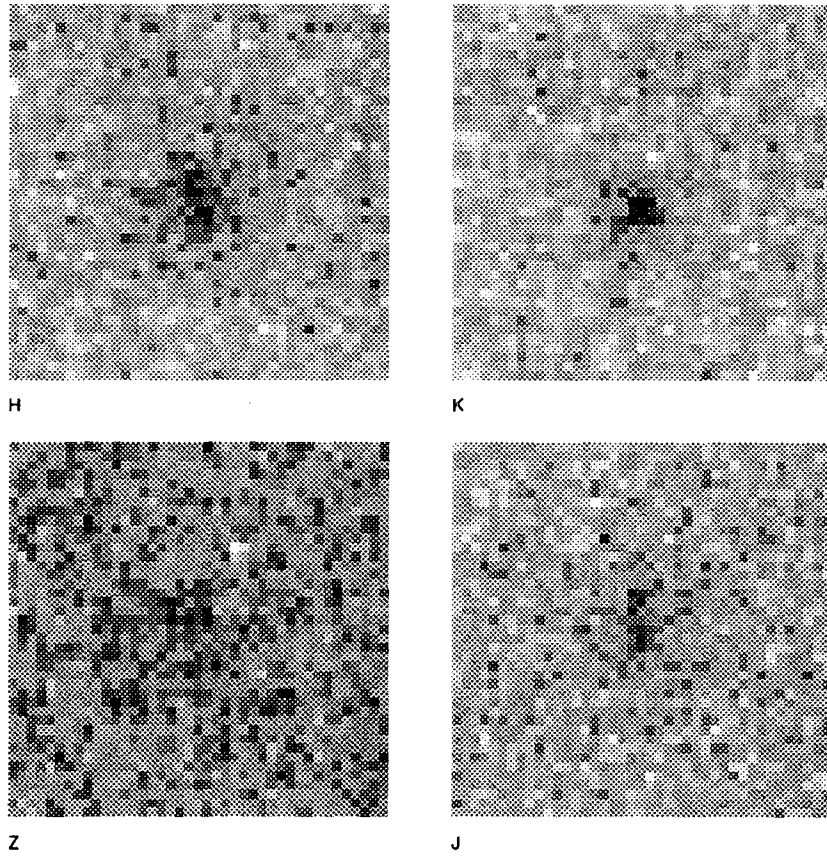


Fig. 6.— The four near-IR images of the brown dwarf candidate Re 77 #1. The filter is identified at the bottom left of each image. The Z-band image shows no detection.

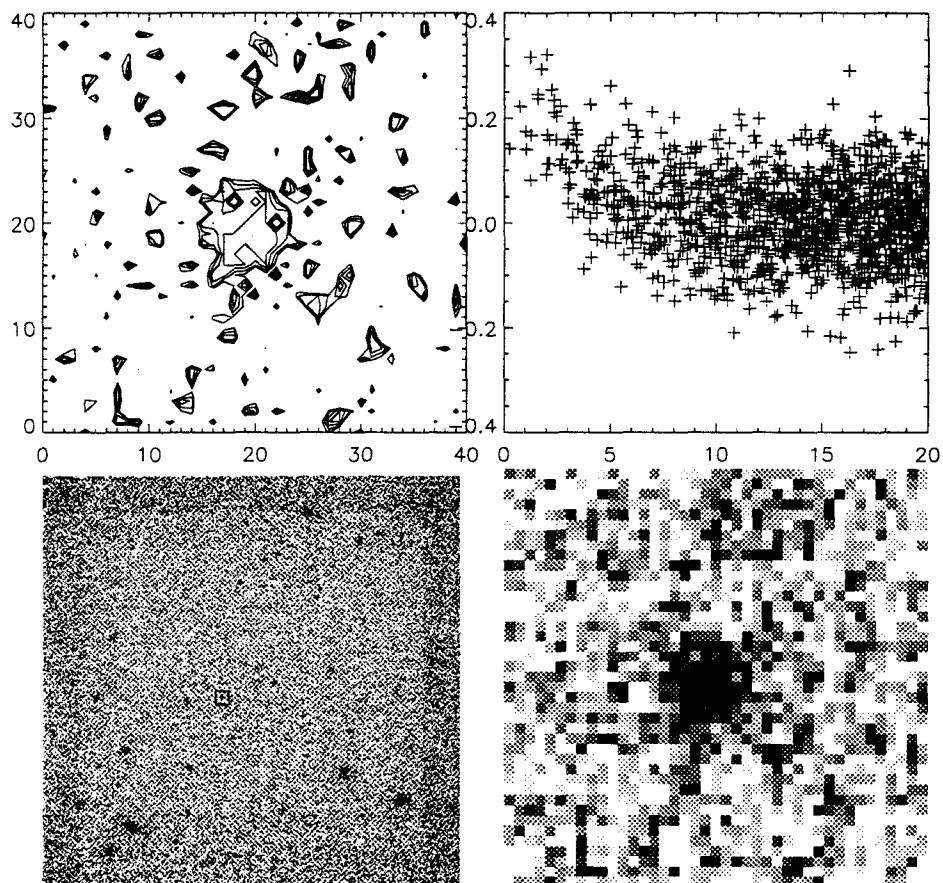


Fig. 9.— Re 77 *K*-data. (BL) the reduced mosaic. (BR) magnified region around the brown-dwarf candidate. (TL) contour plot of the region in BR. (TR) Radial profile of the object with a best-fit stellar profile.

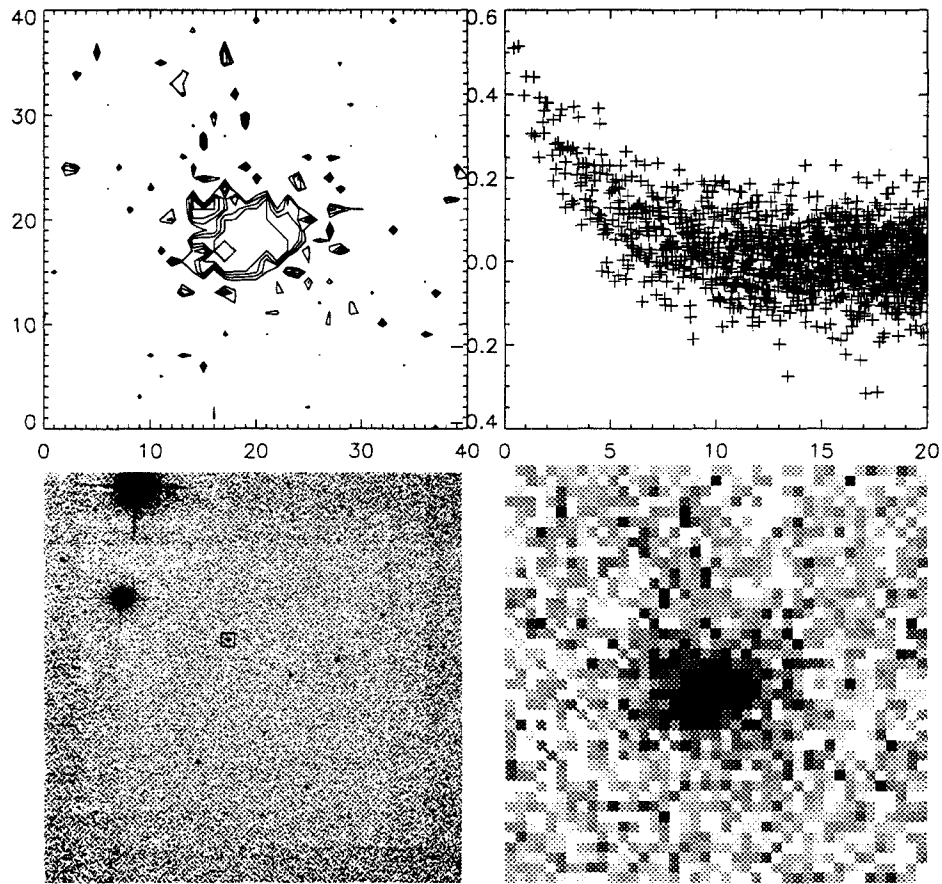


Fig. 12.— GH 7-89 #1 K-band data. The four panels are similar to the previous figures on Re 77.

Table 2. Astrometry of the brown-dwarf candidates.

Pointing	beam	α_{2000}	δ_{2000}
Re 77#1:			
1 st	ON	04:08:23.60	+11:48:04.12
1 st	OFF	04:08:23.53	+11:48:03.61
2 nd	ON	04:08:23.80	+11:48:08.65
2 nd	OFF	04:08:23.25	+11:48:07.21
	mean	04:08:23.55	+11:48:05.90
	error	1.97''	1.40''
GH 7-89#1:			
1 st	ON	04:06:00.16	+18:14:14.68
1 st	OFF	04:06:00.47	+18:14:20.36
2 nd	ON	04:06:00.18	+18:14:17.76
2 nd	OFF	04:06:00.20	+18:14:17.59
	mean	04:06:00.25	+18:14:17.55
	error	1.26''	1.38''

Table 3. Photometry of program objects.

object	J (mag)	H (mag)	K (mag)	ISO (mag)	ISO filter
Re 77 #1	21.11±0.30	19.78±0.20	19.53±0.29	13.99±0.62	LW2
GH 7-89 #1	20.69±0.20	19.63±0.18	18.76±0.20	15.33±0.51	LW1

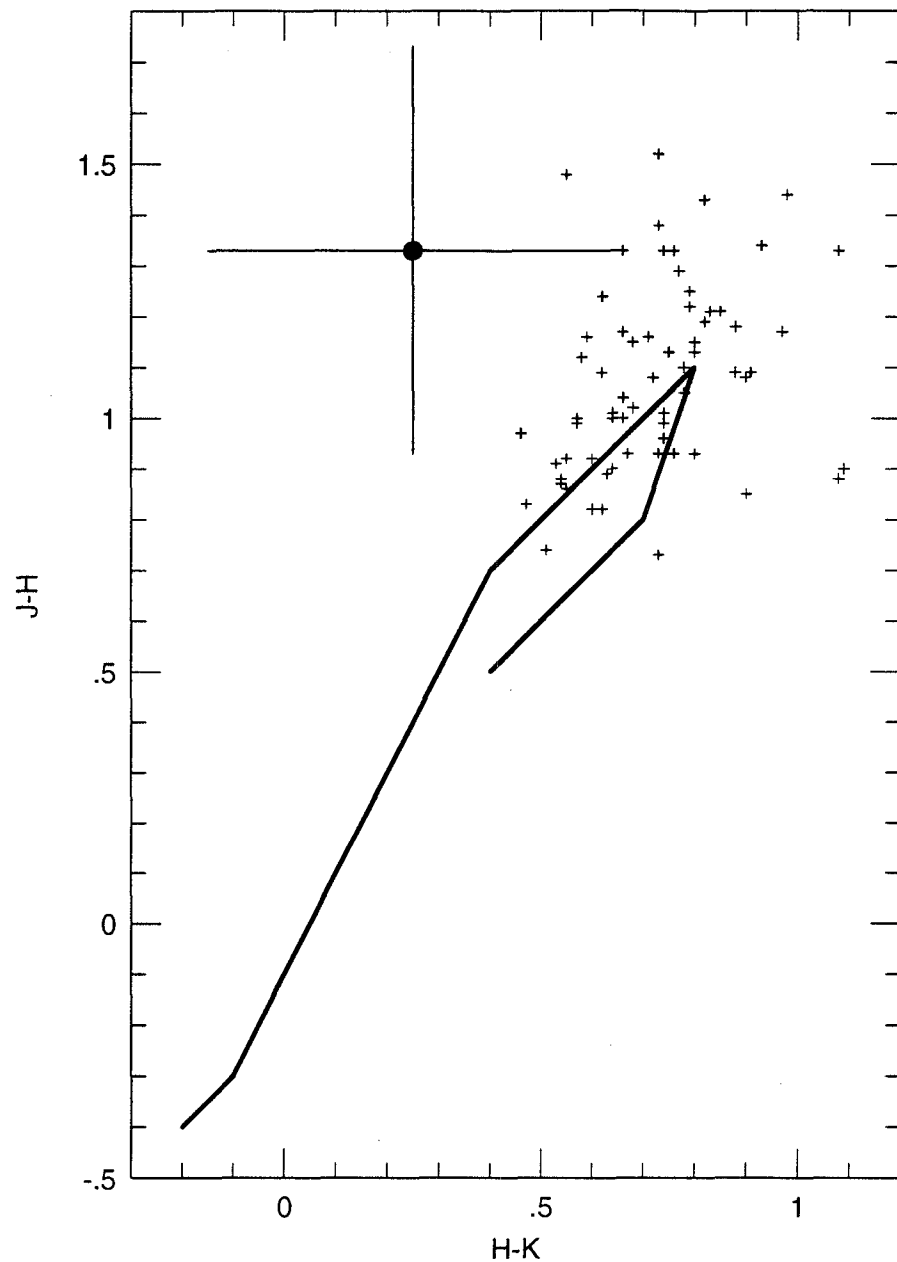


Fig. 11.— The $J-H$ vs $H-K$ color-color diagram for L and T dwarfs. The L and T dwarf sequence is shown by the solid line. The “turn-over” occurs near L8. The pluses are data from Davy Kirkpatrick (private communication) for 2MASS L-dwarfs. The solid point is Re 77 #1.